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MHD FREE CONVECTIVE HEAT AND MASS TRANSFER FLOW PAST AN ACCELERATED VERTICAL PLATE THROUGH A POROUS MEDIUM WITH HALL CURRENT, ROTATION AND SORET EFFECTS

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ABSTRACT

The free convective heat and mass transfer of viscous, incompressible, of unsteady rotating MHD flow past an infinite vertical plate was considered under the influence of Hall current, rotation and Soret effects. It is assumed that the flow possess an angular velocity ω about the normal to the plate. Transverse magnetic field was applied along the normal to the plate. The governing non linear coupled partial differential equations are reduced to dimensionless form using non – dimensional scheme and then solved analytically using two term perturbation method.

KEYWORDS: Porous Medium, MHD, Hall Current, Rotation & Soret Effect

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Original Article

NOMENCLATURE

g	Acceleration due to gravity
Kr'	Chemical reaction parameter
C'	Concentration of the fluid
ρ	Density of the fluid
$\vec{j}$	Electric current density vector
σ	Electrical conductivity
T'	Fluid temperature
m	Hall current parameter
$\vec{E}$	Intensity vector of the electric field
ν	Kinematic viscosity
$\vec{B}$	Magnetic induction vector
M^2	Magnetic parameter
D_M	Mass diffusive coefficient

φ	Non dimensional concentration
K_1	Non dimensional permeability parameter
θ	Non dimensional temperature
n_e	Number density of the electron
K_1'	Permeability of the porous medium
Pr	Prandtl number
N	Radiation parameter
$q_{r'}$	Radiative heat flux
k_1	Roseland mean absorption coefficient
K^2	Rotation parameter
Sc	Schmidt number
Gm	Solutal grashof number
Sr	Soret number
c_p	Specific heat at constant pressure
σ_1	Stephen - Boltzmann coefficient
T_M	The mean fluid temperature
k	Thermal conductivity
K_T	Thermal diffusion ratio
Gr	Thermal grashof number
u'	Velocity of the fluid in x' direction
w'	Velocity of the fluid in z' direction
$\vec{V}$	Velocity vector
β'	Volumetric coefficient of concentration
β	Volumetric coefficient of thermal expansion

INTRODUCTION

In many natural phenomena simultaneous action of thermal and solutal buoyancy forces acting over bodies with different geometries in a fluid with porous medium induces natural convection. That is why it has wide range of industrial applications. For example due to the presence of foreign mass either naturally or mixed with industrial emissions pure water occurrence is impossible. The natural phenomena like vaporization of mist and fog, photosynthesis, transpiration, sea-wind formation, drying of porous solids, and formation of ocean currents [1] occur due to thermal and solutal buoyancy forces. These forces develops due to difference temperatures and concentrations or a combination of these two. Practically such situations arise in the systems of industrial applications like cooling of molten metal's, heat exchanger devices, petroleum reservoirs, insulation systems, filtration, nuclear waste repositories, chemical catalytic reactors and processes, desert coolers, frost formation in vertical channels, wet bulb thermometers, etc. Keeping in view the importance of such flows research work has been done exhaustively by several researchers [2-10] previously. Considerable attention has drawn by the good number of researchers for the investigation of hydro magnetic natural convection flow with heat and mass transfer in porous and non-porous media due to its applications in geophysics, astrophysics, aeronautics, meteorology, electronics, chemical, and metallurgy and petroleum industries. The presence of a magnetic field can prevent natural convection currents and the magnetic field strength is one of the important factors in reducing non-uniform composition thereby enhancing quality of the crystal. This was found by Oreper and Szekely [11]. In addition to this the mass transfer in MHD flow meters, MHD energy generators, MHD pumps, MHD accelerators etc. Due to the above said realistic applications Hossain and Mandal [12], investigated mass transfer effects on unsteady hydro magnetic free convective flow of an accelerated vertical porous plate. Analysis of hydro magnetic free convection and mass transfer flow past a uniformly accelerated vertical plate through a porous medium when magnetic field is fixed with the moving plate was done by Jha [13]. A detailed analysis of heat and mass transfer along a vertical plate in the presence of magnetic field was done by Elbashbeshy [14]. Combined heat and mass transfer analysis in MHD free convection flow from a vertical surface with Ohmic heating and viscous dissipation was done by Chen [15]. Unsteady MHD micropolar fluid flow and heat transfer past a vertical porous plate through a porous medium in the presence of thermal and mass diffusions with a constant heat source, was done by Ibrahim et al.[16]. Chamkha [17] investigated unsteady MHD convective flow with heat and mass transfer past a semi-infinite vertical permeable moving plate in a uniform porous medium with heat absorption. Makinde and Sibanda [18] investigated MHD mixed convection flow with heat and mass transfer past a vertical plate embedded in a uniform porous medium with constant wall suction in the presence of uniform transverse magnetic field. Makinde [19] studied MHD mixed convection flow and mass transfer past a vertical porous plate embedded in a porous medium with constant heat flux. Eldabe et al. [20] discussed unsteady MHD flow of a viscous and incompressible fluid with heat and mass transfer in a porous medium near a moving vertical plate with time-dependent velocity.

Hydromagnetic natural convection flow in a rotating medium has great significance due to its vast applications in various areas of astrophysics, geophysics and fluid engineering viz. maintenance and secular variations in Earth's magnetic field due to motion of Earth's liquid core, structure of the magnetic stars, internal rotation rate of the Sun, turbo- machines, solar and planetary dynamo problems, rotating drum separators for liquid metal MHD applications, rotating MHD generators, etc. Number of researchers such as Singh [21,22], Raptis and Singh [23], Kythe and Puri [24], Tokis [25], Nanousis [26] and Singh et al. [27], studied the importance of, unsteady hydromagnetic natural convection flow past a moving plate in a rotating medium. Thermal radiation effects are not considered in the above said investigations. The effect of thermal radiation on hydromagnetic natural convection flow with heat and mass transfer is significant in manufacturing

processes viz. glass Production, the design of fins, steel rolling, furnace design, casting and levitation, etc. Moreover, several engineering processes like Nuclear power plants, gas turbines and various propulsion devices for missiles, aircraft, satellites and space vehicles [28] occur at very high temperatures where the knowledge of radiative heat transfer becomes indispensiable for the design of the pertinent equipment. One has to note that unlike convection/conduction the governing equations taking into account the effects of thermal radiation become quite complicated. Therefore, some reasonable approximations are proposed to solve the governing equations with radiative heat transfer. Viskanta and Grosh [29] initiated to investigate the effects of thermal radiation on temperature distribution and heat transfer in an absorbing and emitting media flowing over a wedge. They used Roseland approximation for the radiative heat flux vector to simplify the energy equation. Later several authors [30-36] studied the effect of thermal radiation on MHD flows.

In the above studies, Hall current was ignored. But the effects of Hall current are significant in the presence of strong magnetic field [37]. Due to this, research being carried towards MHD flows having a strong magnetic field. An ionized gas of low density subjected to a strong magnetic field, the conductivity perpendicular to the magnetic field is decreased by free spiral movement of electrons and ions about the magnetic lines of force before suffering collisions. A current produced in a direction at right angle to the electric and magnetic fields is called Hall current. In MHD power generators and pumps, Hall accelerators, refrigeration coils, electric transformers, in-flight MHD, solar physics involved in the sunspot development, the solar cycle, the structure of magnetic stars, electronic system cooling, cool combustors, fiber and granular insulation, oil extraction, thermal energy storage and flow through filtering devices and porous material regenerative heat exchangers, we come across with the effects of Hall current. For the low density of the electrically conducting fluid or strong applied magnetic field, Hall current will play a vital role in determining the features of the flow field. Keeping in view of the above fact investigations on hydromagnetic free convection flow past a flat plate with Hall effects under different thermal conditions are carried out by several researchers in the past. The research studies were done by Pop and Watanabe [38], Abo-Eldahab and Elbarbary [39], Takhar et al. [40] and Saha et al. [41]. Satya Narayana et al. [42] studied the effects of Hall current and radiation–absorption on MHD natural convection heat and mass transfer flow of a micropolar fluid in a rotating frame of reference. Seth et al. [43] investigated effects of Hall current and rotation on unsteady hydromagnetic natural convection flow of a viscous, incompressible, electrically conducting and heat absorbing fluid past an impulsively moving vertical plate with ramped temperature in a porous medium taking into account the effect of thermal diffusion. Seth et al. [44] investigated the effects of Hall current, thermal radiation and rotation on natural convection heat and mass transfer flow past a moving vertical plate. Takhar et al. [45] investigated the effect of Hall current on MHD flow over a moving plate in a rotating fluid with the magnetic field and free stream velocity.

The present study deals with the study of the effects of Hall current, rotation and Soret effect on an unsteady MHD free convection flow of a viscous, incompressible, electrically conducting fluid past an impulsively moving vertical plate in a porous medium. The governing equations are first transformed into a set of normalized equations and then solved analytically by using two-term perturbation technique. The influence of different parameters involved in velocity, temperature and concentration distributions are analyzed and discussed graphically.

FORMULATION OF THE PROBLEM

Unsteady MHD natural convection flow with heat and mass transfer of an electrically conducting, viscous, incompressible fluid past an infinite vertical plate embedded in a uniform porous medium in a rotating system taking Hall current into account. Assuming Hall currents, the generalized Ohm's law [46] may be redrafted in the following form,

$$\vec{j} = \frac{\sigma}{1+m^2}\left(\vec{E} + \vec{V}\times\vec{B} - \frac{1}{\sigma n_e}\vec{j}\times\vec{B}\right)$$

The interesting fact is that presence of Hall current produces force in z' direction, which produces cross flow velocity, so that the flow becomes three dimensional.

In the present analysis we made the following assumptions.

- The plate was along x' axis in the upward direction.
- Transverse magnetic field B_0 was applied parallel to y' - axis.
- The flow produces angular velocity along normal to the plate.
- Initially i.e at time $t' \le 0$ the plate as well as the fluid are in rest and maintained at uniform temperature T_∞'.
- Also species concentration at the surface of the plate as well as at every point within the fluid is maintained at uniform concentration C_∞'.
- At time $t > 0$, plate starts moving in x' -direction with a velocity $u' = Ut'$ in its own plane.
- The temperature at the surface of the plate is raised to uniform temperature T_w' and species concentration at the surface of the plate is raised to uniform species concentration C_w'.
- Since the plate is of infinite length along x' and z' directions and is electrically non conducting, all physical quantities except pressure, depends on y' and t'.
- As there are no polarized voltages, polarized voltages can be neglected.
- The induced magnetic field generated by fluid motion is negligible in comparison to the applied one. This assumption is justified because for liquid metals and partially ionized fluids which are commonly used in industrial applications [47], magnetic Reynolds number is very small.

Sarma et al.[48] solved the problem using Laplace transform technique. But here we are solving the problem through two-term perturbation technique

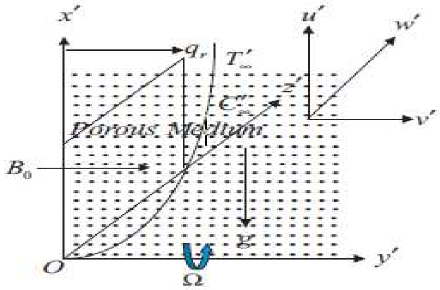

Figure 1: Geometry of the Problem

With the above assumptions made above, governing equations for momentum, energy and species concentration are given by,

$$\frac{\partial u'}{\partial t'}+2\omega w'=\nu\frac{\partial^2 u'}{\partial y'^2}-\frac{\sigma B_0{}^2}{\rho\left(1+m^2\right)}(u'+mw')+g\beta\left(T'-T_\infty{}'\right)+g\beta(C'-C_\infty)-\frac{\nu u'}{k_1'} \tag{1}$$

$$\frac{\partial w'}{\partial t'}-2\omega u'=\nu\frac{\partial^2 w'}{\partial y'^2}+\frac{\sigma B_0{}^2}{\rho\left(1+m^2\right)}(mu'-w')-\frac{\nu w'}{k_1'} \tag{2}$$

$$\frac{\partial T'}{\partial t'}=\frac{k}{\rho c_p}\frac{\partial^2 T'}{\partial y'^2}-\frac{1}{\rho c_p}\frac{\partial q_r{}'}{\partial y'} \tag{3}$$

$$\frac{\partial C'}{\partial t'}=D_M\frac{\partial^2 C}{\partial y^2}+\frac{D_M K_T}{T_M}\frac{\partial^2 T'}{\partial y'^2}-k_r{}'\left(C'-C_\infty{}'\right) \tag{4}$$

The corresponding initial and boundary conditions for the flow are given by

$$u'=w'=0, T'=T_\infty{}', C'=C_\infty{}' \text{ for all } y' \text{ and } t'\le 0 \tag{5}$$

$$u'=Ut', w'=0, T'=T_w{}', C'=C_w{}' \text{ at } y'=0 \text{ for } t'\ge 0 \tag{6}$$

$$u'\to 0, w'\to 0, T'\to T_\infty{}', C'\to C_\infty{}', \text{ as } y'\to\infty \text{ for } t>0 \tag{7}$$

The absorption coefficient of the fluid is so large, so using Roseland approximation the radiative heat flux is given by $q_r{}'=-\frac{4\sigma_1}{3k_1}\frac{\partial T'^4}{\partial y'}$ (8)

Assuming temperature difference is sufficiently small, we can express T'^4 using Taylor's series expansion about T_∞ neglecting higher order terms as follows

$$T'^4\approx 4T_\infty{}'^3T'-3T_\infty{}'^4 \tag{9}$$

Using (8) and (9), (3) transformed to

$$\frac{\partial T'}{\partial t'}=\frac{k}{\rho c_p}\frac{\partial^2 T'}{\partial y'^2}+\frac{16\sigma_1 T_\infty{}'^3}{3k_1\rho c_p}\frac{\partial^2 T'}{\partial y'^2} \tag{10}$$

Introducing the following non-dimensional quantities:

$$u=\frac{u'}{U_0}, w=\frac{w'}{U_0}, y=\frac{y'U_0}{\nu}, t=\frac{t'U_0{}^2}{\nu}, \theta=\frac{T'-T_\infty{}'}{T_w{}'-T_\infty{}'}$$

$$\varphi = \frac{C' - C_\infty'}{C_w' - C_\infty'}, Gr = \frac{g\beta\nu\left(T_w' - T_\infty\right)}{U_0^{\ 3}}, Gm = \frac{g\beta'\nu\left(C_w' - C_\infty'\right)}{U_0^{\ 3}}$$

$$\Pr = \frac{\mu c_p}{k}, k'^2 = \frac{\nu\Omega}{U_0^{\ 2}}, Sc = \frac{\nu}{D_M}, kr = \frac{\nu kr'}{U_0^{\ 2}} \tag{11}$$

$$M^2 = \frac{\sigma B_0^{\ 2}\nu}{\rho U_0^{\ 2}}, U = \frac{U_0^{\ 3}}{\nu}, N = \frac{kk_1}{4\sigma_1 T_\infty'^3}, \lambda = \frac{(3N+4)}{3N}$$

$$Sr = \frac{D_M K_T\left(T_w' - T_\infty'\right)}{\nu T_M\left(C_w' - C_\infty'\right)}, k_1 = \frac{k_1' U_0^{\ 2}}{\nu^2}$$

Equations (1) (2) (4) and (8) in the non dimensional form are

$$\frac{\partial u}{\partial t} + 2K^2 w = \frac{\partial^2 u}{\partial y^2} - \frac{M^2}{(1+m^2)}(u + mw) + Gr\theta + Gm\varphi - \frac{u}{K_1} \tag{12}$$

$$\frac{\partial w}{\partial t} - 2K^2 u = \frac{\partial^2 w}{\partial y^2} + \frac{M^2}{\left(1+m^2\right)}(mu - w) - \left(\frac{w}{K_1}\right) \tag{13}$$

$$\frac{\partial \theta}{\partial t} = \frac{\lambda}{\Pr}\frac{\partial^2 \theta}{\partial y^2} \tag{14}$$

$$\frac{\partial \varphi}{\partial t} = \frac{1}{Sc}\frac{\partial^2 \varphi}{\partial y^2} + Sr\frac{\partial^2 \theta}{\partial y^2} - Kr\varphi \tag{15}$$

The transformed boundary and initial conditions are

$$u = w = 0, \theta = 0, \varphi = 0 \ \forall y \text{ and } t \le 0 \tag{16}$$

$$u = t, w = 0, \theta = 1, \varphi = 1 \text{ at } y = 0 \text{ and } t > 0 \tag{17}$$

$$u \to 0, w \to 0, \theta \to 0, \varphi \to 0 \text{ as } y \to \infty \text{ and } t > 0 \tag{18}$$

We can rewrite the equations (12) and (13) in compact form

$$\frac{\partial F}{\partial t} = \frac{\partial^2 F}{\partial y^2} - \alpha F + Gr\theta + Gm\varphi \tag{19}$$

Where $F = u + iw$ and $\alpha = \dfrac{M^2(1-im)}{(1+m^2)} + \dfrac{1}{K_1} - 2iK^2$ (20)

The initial and boundary conditions in compact form

$$F = 0, \theta = 0, \varphi = 0 \;\forall y \text{ and } t \le 0 \tag{21}$$

$$F = t, \theta = 1, \varphi = 1 \text{ at } y = 0 \text{ and } t > 0 \tag{22}$$

$$F \to 0, \theta \to 0, \varphi \to 0 \text{ as } y \to \infty \text{ and } t > 0 \tag{23}$$

SOLUTION OF THE PROBLEM

Equations (14), (15) and (19) are coupled non – linear and hence the exact solution is not available. However, these equations can be reduced to set of ordinary differential equations which can be solved analytically. This is possible by representing velocity, temperature and concentration in the neighborhood of the plate as

$$F(y,t) = F_0(y) + \varepsilon e^{Kt} F_1(y) + O(\varepsilon)^2 \tag{24}$$

$$\theta(y,t) = \theta_0(y) + \varepsilon e^{Kt} \theta_1(y) + O(\varepsilon)^2 \tag{25}$$

$$\varphi(y,t) = \varphi_0(y) + \varepsilon e^{Kt} \varphi_1(y) + O(\varepsilon)^2 \tag{26}$$

Substituting equations (24) – (26) in (19), (14) and (15) respectively, comparing harmonic and non-harmonic terms, neglecting higher order terms $O(\varepsilon)^2$, we obtain

$$F_0'' - \alpha F_0 = -Gr\theta_0 - Gm\varphi_0 \tag{27}$$

$$F_1'' - (\alpha + K) F_1 = -Gr\theta_1 - Gm\varphi_1 \tag{28}$$

$$\theta_0'' = 0 \tag{29}$$

$$\theta_1'' - \frac{\Pr K}{\lambda}\theta_1 = 0 \tag{30}$$

$$\varphi_0'' - KrSc\varphi_0 = -ScSr\theta_0'' \tag{31}$$

$$\varphi_1'' - (Kr - K)\varphi_1 = -Sr\theta_1'' \tag{32}$$

The solutions of (19), (14) and (15) in the explicit form are

$$F(y,t)=\left(t+\frac{(\gamma-i\delta)}{(\gamma^2+\delta^2)}Gm\right)e^{-\sqrt{\alpha}y}-\frac{(\gamma-i\delta)}{(\gamma^2+\delta^2)}Gme^{-\sqrt{KrSc}y}$$
$$+\varepsilon e^{Kt}\left\{\begin{array}{l}\left[\frac{(F-iG)Gr}{(F^2+G^2)}+\frac{GmSr\Pr k}{\Pr K-\lambda A}\left(\frac{(S-iT)}{(S^2+T^2)}-\frac{(E-iD)}{(E^2+D^2)}\right)\right]e^{-\sqrt{\alpha+K}y}-\\ \frac{(F-iG)Gr}{(F^2+G^2)}e^{-\sqrt{\frac{\Pr K}{\lambda}}y}-\\ \frac{GmSr\Pr k}{\Pr K-\lambda A}\frac{(S-iT)}{(S^2+T^2)}e^{-Ay}+\frac{GmSr\Pr k}{\Pr K-\lambda A}\frac{(E-iD)}{(E^2+D^2)}e^{-By}\end{array}\right\} \tag{33}$$

$$\theta(y,t)=e^{Kt}e^{-\sqrt{\frac{\Pr K}{\lambda}}y} \tag{34}$$

$$\varphi(y,t)=e^{-\sqrt{KrSc}y}+\varepsilon e^{Kt}\frac{Sr\Pr K}{\Pr K-\lambda A}\left(e^{-Ay}-e^{-By}\right) \tag{35}$$

The physical quantities of engineering interest are skin friction, Nusselt number and Sherwood number.

SKIN FRICTION

Skin friction measures the rate of shear stress at the plate due to primary flow and secondary flow which is given as below

$$\left.\frac{\partial F}{\partial y}\right|_{y=0}=\tau_x+i\tau_z \tag{36}$$

Nusselt Number

Nusselt number gives the rate of heat transfer at the plate and is given as

$$Nu=\left.\frac{\partial\theta}{\partial y}\right|_{y=0} \tag{37}$$

Sherwood Number

Sherwood number measures the rate of mass transfer at the plate given by

$$sh=\left.\frac{\partial\varphi}{\partial y}\right|_{y=0} \tag{38}$$

RESULTS AND DISCUSSIONS

In order to understand the physics of the problem and analyzing the effects of Hall current, rotation, Thermal radiation, thermal buoyancy force, concentration buoyancy force, mass diffusion, thermal diffusion, chemical reaction, Soret number and time on the flow field, numerical values of the primary and secondary fluid velocities in the boundary layer region were computed from the analytical solution (33) and are displayed graphically.

Figures 1 – 14 reveals influence of thermal grash of number Gr solutal Grashof number Gm, hall current parameter m rotation parameter K^2, Schmidt number Sc, permeability parameter K_1, chemical reaction parameter Kr. Figures 1 and 2 shows that primary and secondary velocities decreases with increase of Gr. Figures 3 and 4 depicts increase of Gm results in increase of u and w. Gm represents relative strength of concentration buoyancy forces to viscous force. From figures 3 and 4 it is evident that Gm accelerates primary and secondary velocities of the flow. Figures 5 and 6 shows that increase of Hall current results in decrease of primary velocity u and increase of secondary velocity w. This reveals the fact that Hall current m induces secondary velocity of the rotation flow and shows the reverse effect onprimary velocity. It is evident from figures 7 and 8 that increase of rotation parameter K^2 leads to decrease of primary velocity u and increase in secondary velocity w of the flow. This reflects the fact that rotation parameter retards the fluid in the primary flow direction, where as accelerates fluid flow in the secondary flow direction. Figures 9 and 10 shows those primary, secondary velocities of the flow decreases, with increase of Schmidt number Sc. The reduction in two types of velocities and concentration are accompanied by permeability of the porous medium. This can be observed from the figures 11 and 12. It is noticed that increase permeability parameter enhance the velocity of the flow field in secondary direction, whereas decreases the velocity in primary direction. Figures13 and 14 depicts influence of chemical reaction parameter kr on primary and secondary velocities. It is noticed that increase of kr results in decrease of primary velocity. This was due to the increase in diffusion rate. But increase of kr leads to increase of secondary velocity w.

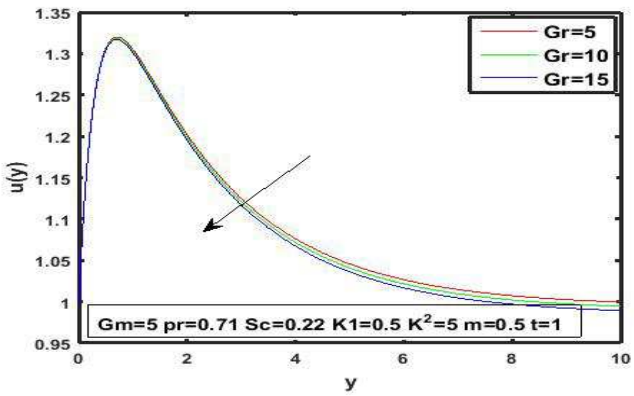

Figure 1: Contribution of Thermal Grash of Number on Primary Velocity

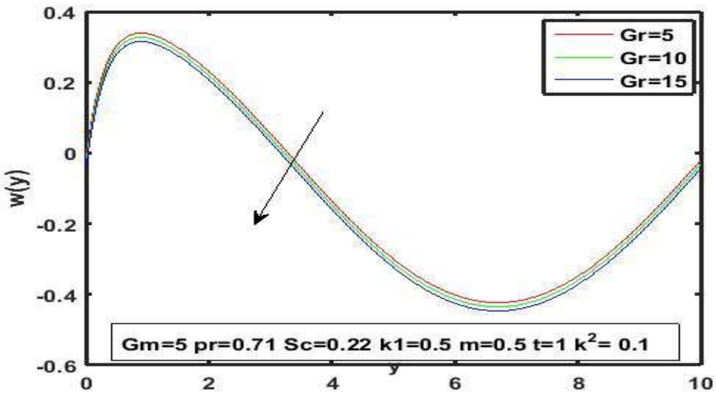

Figure 2: Contribution of Thermal Grash of Number on Secondary Velocity

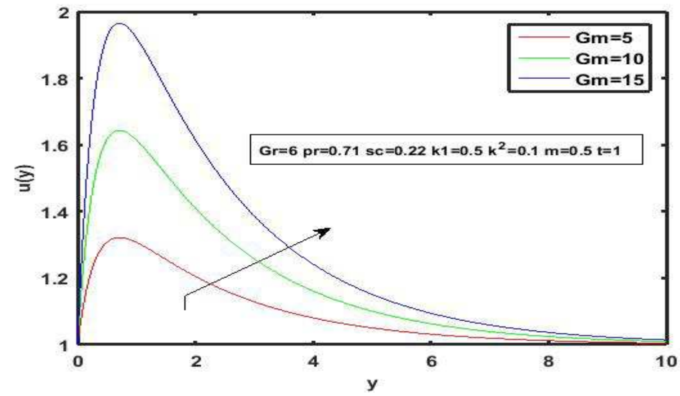

Figure 3: Contribution of Solutal Grash of Number on Primary Velocity

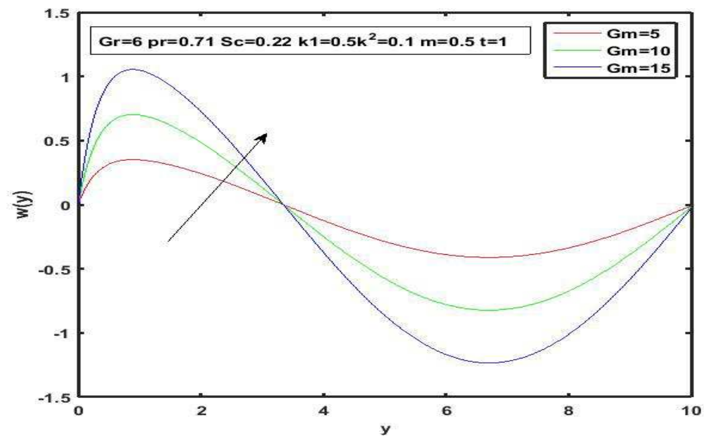

Figure 4: Contribution of Solutal Grash of Number on Secondary Velocity

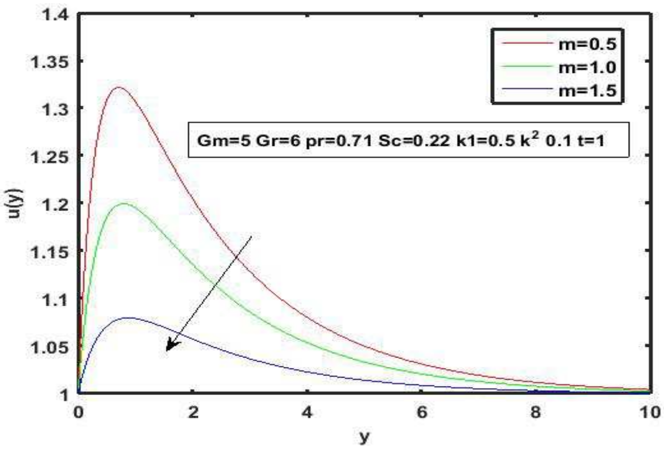

Figure 5: Contribution of Hall Current Parameter on Primary Velocity

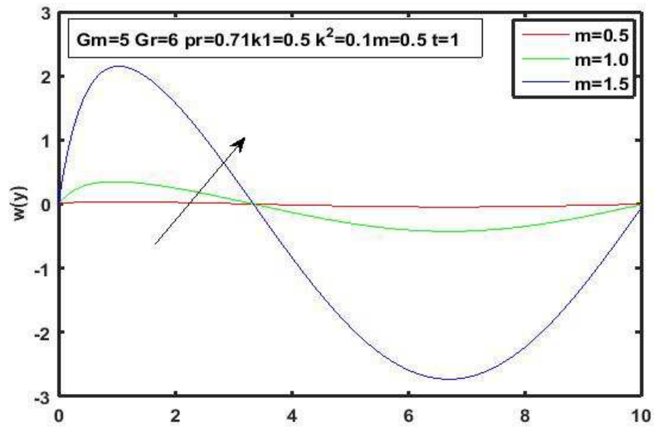

Figure 6: Contribution of Hall Current Parameter on Secondary Velocity

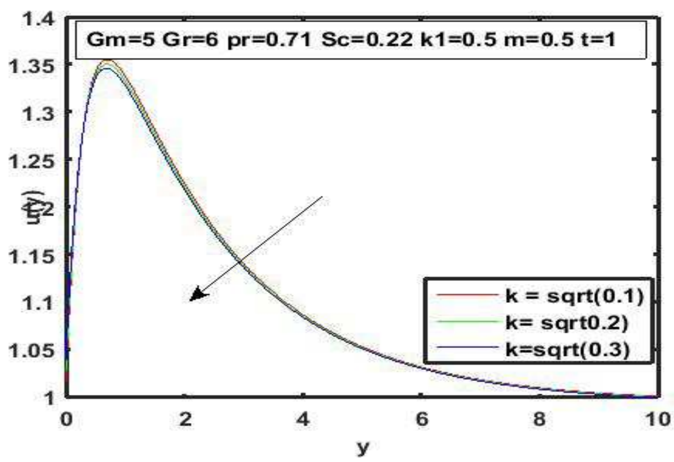

Figure 7: Contribution of Rotation Parameter on Primary Velocity

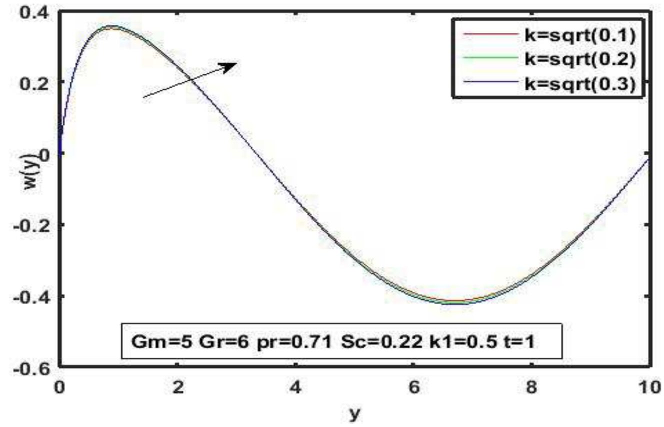

Figure 8: Contribution of Rotation Parameter on Secondary Velocity

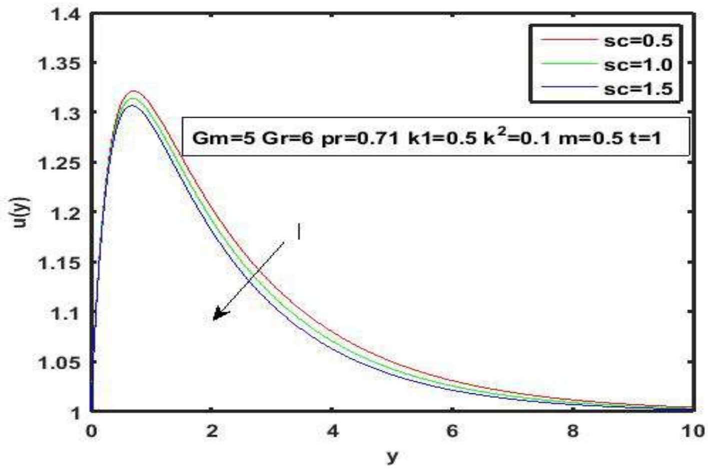

Figure 9: Contribution of Schmidt Number on Primary Velocity

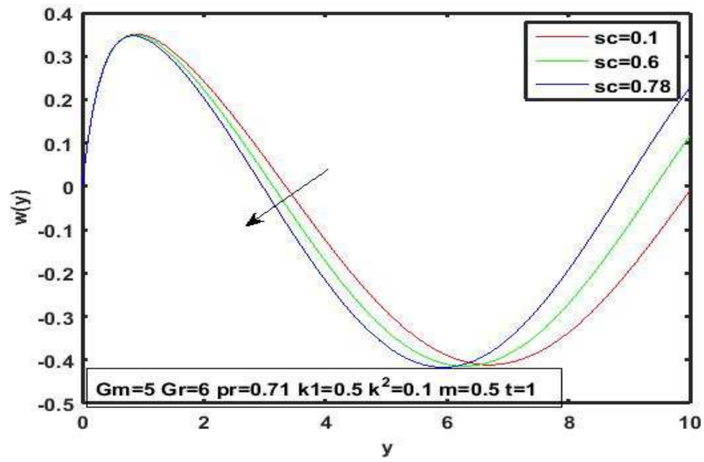

Figure 10: Contribution of Schmidt Number on Secondary Velocity

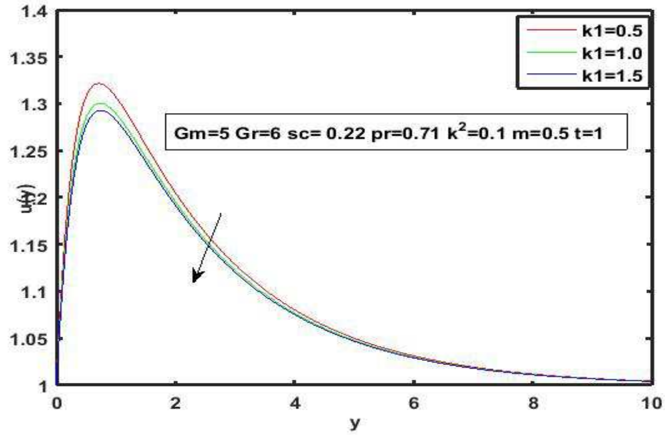

Figure 11: Contribution of Permeability Parameter on Primary Velocity

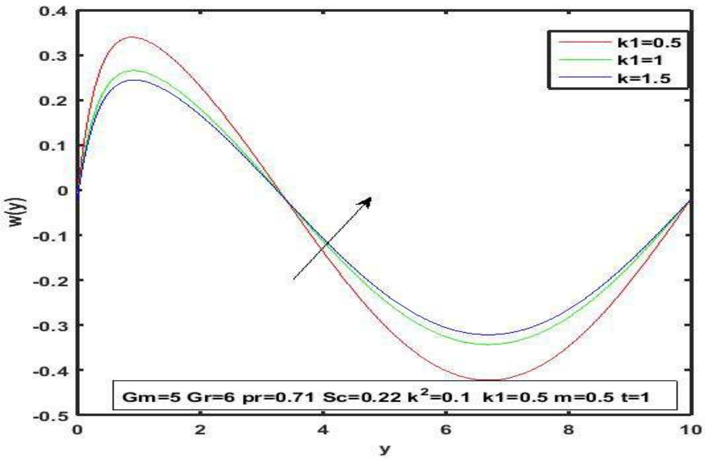

Figure 12: Contribution of Permeability Parameter on Secondary Velocity

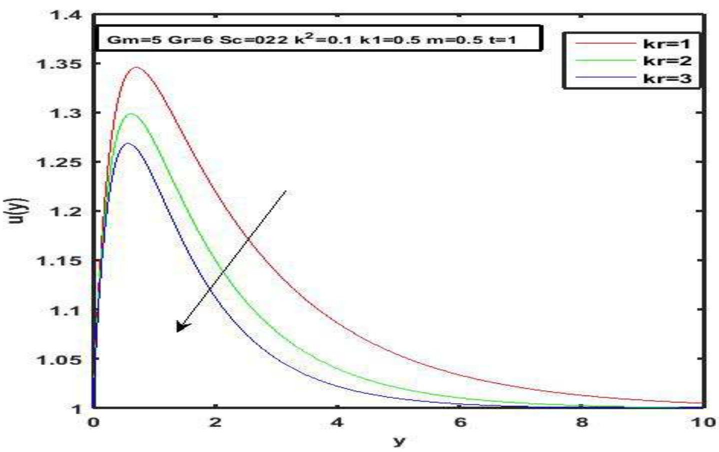

Figure 13: Contribution of Chemical Reaction Parameter on Primary Velocity

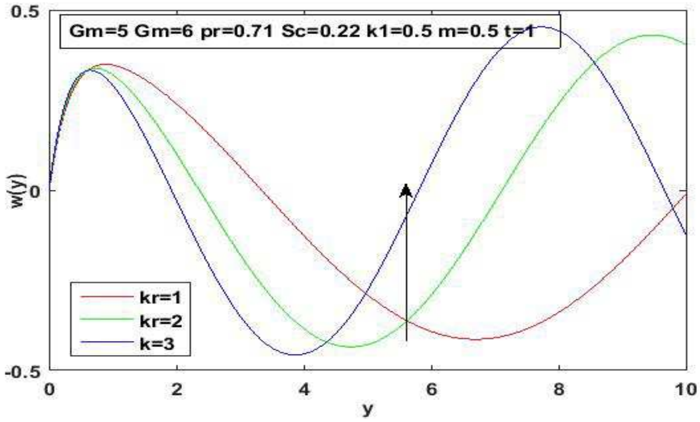

Figure 14: Contribution of Chemical Reaction Parameter on Secondary Velocity

Figures15, 16 and 17 shows the contribution of Prandtl number pr Radiation parameter R and time t on temperature. From the profiles it can be seen that increase of prandtl number and Radiation parameter leads to decrease in temperature. But as the time elapses we can observe the increase in temperature.

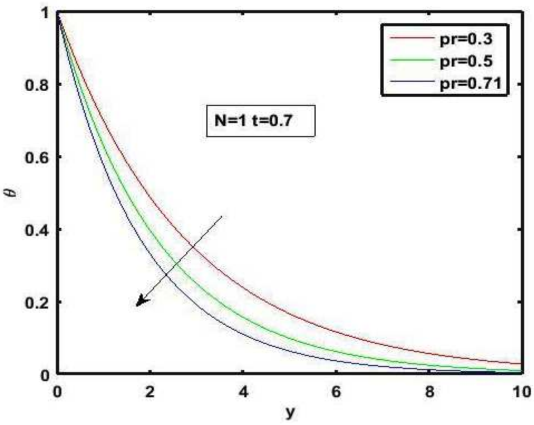

Figure 15: Contribution of Prandtl Number on Temperature

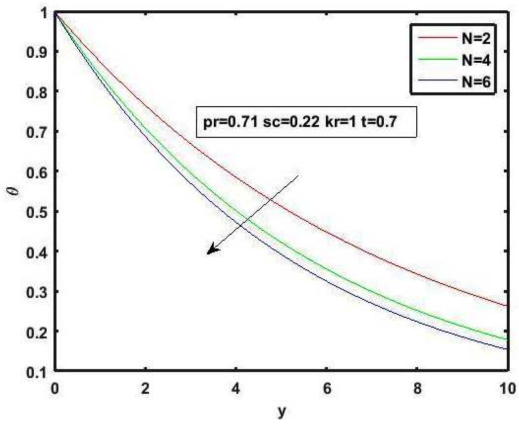

Figure 16: Contribution of Radiation Parameter on Temperature

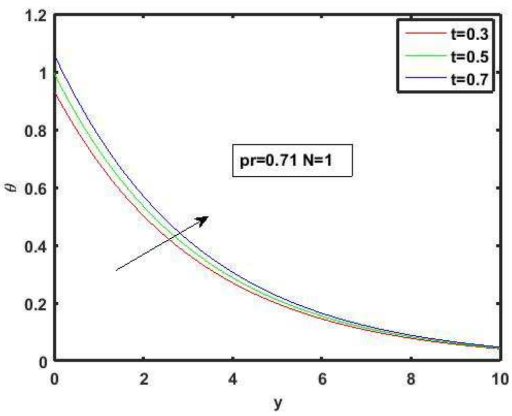

Figure 17: Contribution of Time Parameter on Temperature

Figures 18 19 and 20 shows the influence of chemical reaction parameter on kr, Schmidt number Sc and soret

number sr on concentration of the fluid. From figure 15 we can observe the increase of chemical reaction results in a decrease of concentration. Due to increase in chemical reaction leads high molecular motion. This turn results in decrease of concentration, in the flow. Figure 16 shows that increase of Schmidt number decreases the concentration of the flow. This is because of decrease of molecular diffusivity from the definition. Figure 17 depicts that influence of soret number on concentration profiles. It is seen that increase of soret number gives rise to increase of the concentration of the fluid. This is due to the increase of soret number results in increase of molar mass diffusivity.

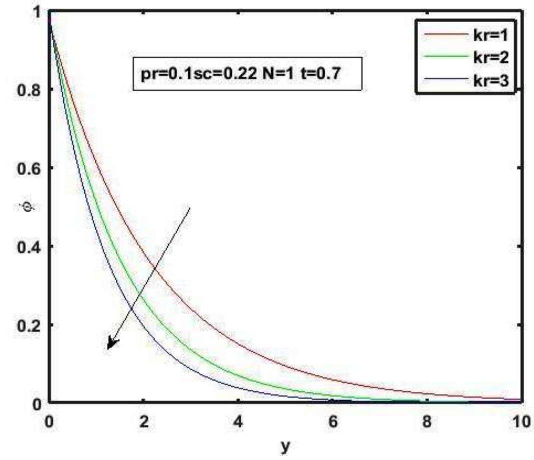

Figure 18: Contribution of Chemical Reaction Parameter on Concentration

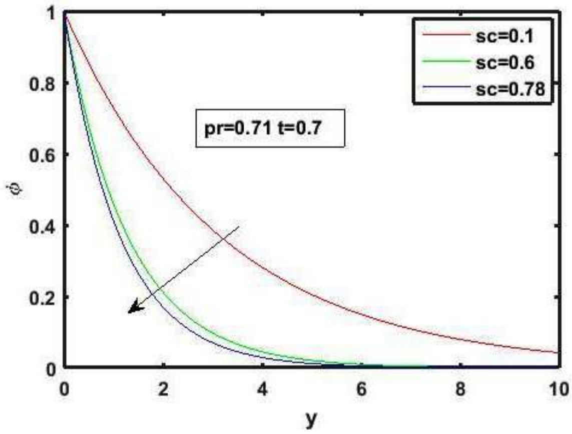

Figure 19: Contribution of Schmidt Number on Concentration

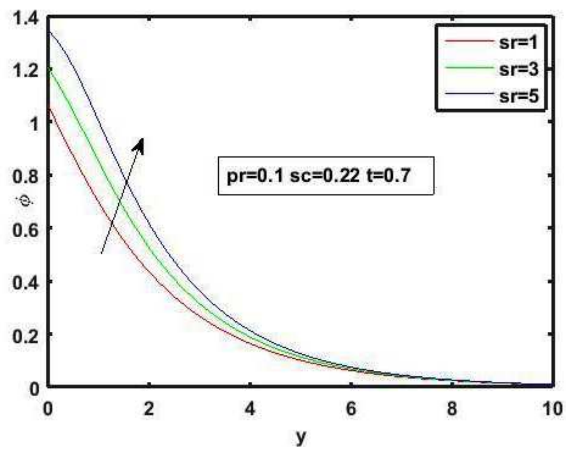

Figure 20: Contribution of Soret Number on Concentration

Table 1

Skin Friction										
Gr	Gm	Sc	K^2	K_1	kr	sr	m	t	τ_x	τ_z
5	5	0.22	0.1	0.5	1	1	0.5	0.5	0.290938	0.060761
10	5	0.22	0.1	0.5	1	1	0.5	0.5	0.290938	0.060761
15	5	0.22	0.1	0.5	1	1	0.5	0.5	0.290938	0.060761
6	5	0.22	0.1	0.5	1	1	0.5	0.5	0.194467	1.050596
5	10	0.22	0.1	0.5	1	1	0.5	0.5	0.194467	1.050596
5	15	0.22	0.1	0.5	1	1	0.5	0.5	0.194467	1.050596

Table 2

Nusselt Number			
pr	N	t	Nu
0.3	1	0.5	0.423985
0.5	1	0.5	0.423985
0.71	1	0.5	0.423985
0.71	2	0.5	0.111254
0.71	4	0.5	0.111254
0.71	6	0.5	0.111254

Table 3

Sherwood Number						
pr	Sc	kr	N	sr	t	sh
0.3	0.22	1	1	1	0.5	0.022762
0.71	0.22	1	1	1	0.5	0.360675
7	0.22	1	1	1	0.5	0.178340
0.71	0.1	1	1	1	0.5	0.042350
0.71	0.22	1	1	1	0.5	0.573302
0.71	0.78	1	1	1	0.5	0.573302

CONCLUSIONS

- Graphical analysis has been done to describe the effect of different physical parameters on the fluid velocity, temperature and species concentration. During the analysis the significant findings are,
- Rotation as well as accelerates the secondary velocity, but decreases the velocity of primary fluid flow
- Concentration buoyancy force enhances the fluid velocity in primary and secondary direction.
- Permeability of the porous medium accelerates the secondary fluid velocity, whereas shows the reverse effect on primary velocity.
- Thermal diffusion and radiation retard the fluid temperature, whereas progress in time enhances the temperature of the fluid.
- Chemical reaction parameter and Schmidt number decrease fluid concentration, and the increase of Soret number the increases fluid concentration.

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APPENDICES

$$A = Kr - K, B = \sqrt{\frac{\Pr K}{\lambda}}$$

$$E = B^2 - \frac{M^2}{1+m^2} + \frac{1}{K_1} - K, D = \frac{M^2 m}{1+m^2} - K^2$$

$$F = \frac{\Pr K}{\lambda} - \frac{M^2}{1+m^2} - \frac{1}{K_1} - K$$

$$G = \frac{M^2 m}{1+m^2} + 2K^2$$

$$S = \left(Kr - K\right)^2 - \frac{M^2}{1+m^2} - \frac{1}{K_1} - K$$

$$T = \frac{m}{1+m^2} - 2K^2$$

$$\alpha = \frac{M^2}{1+m^2} + \frac{1}{K_1} - i\left(\frac{m}{1+m^2} + 2K^2\right)$$

$$\gamma = KrSc - \left(\frac{m}{1+m^2} - \frac{1}{K_1}\right)$$

$$\delta = \frac{M^2 m}{1+m^2} + 2K^2$$